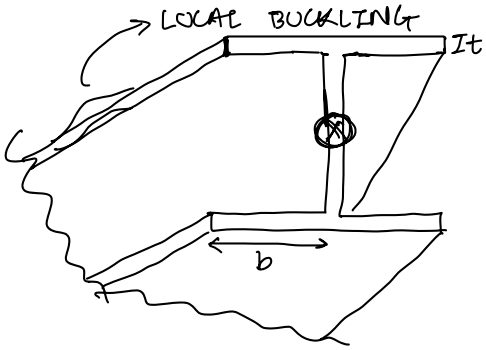
Compression Members

1. Introduction

If primary force is axial compression then member is compression member. If orientation is vertical then column otherwise strut

2. Classification of section

A plate element of a crossection may buckle locally due to compressive stress this local buckling could be avoided before the limit state is achieved by limiting width to thickness ratio of each element of crossection subjected to axial compression, shear or bending.



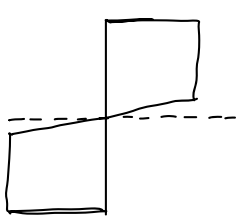
When plastic analysis is used section should be capable of forming plastic hinge without buckling.
When elastic analysis is used section should be capable of developing yield stress before local buckling.

As per IS 800:2007 based on local buckling criteria cross sections are classified in following four types

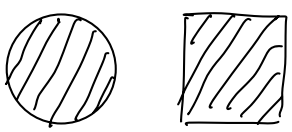
* Plastic section
* Compact section
* Semi-compact section
* Slender section.

PLASTIC SECTION

It developes full plastic moment capacity and has significant rotational capacity that means no local buckling before collapse



stress diagram



plastic section

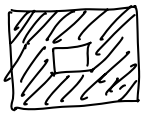
$\theta_2 \geq 6\theta_1$

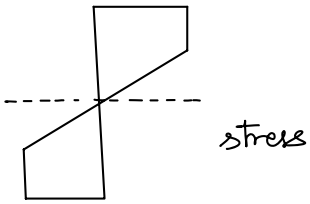
θ_1 = rotation at onset of plasticity
θ_2 = lower limit of rotation for plastic section.

COMPACT SECTION

It developes plastic hinge but has inadequate plastic hinge rotation capacity to form mechanism

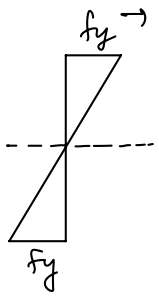
$\theta_2 < 6\theta_1$



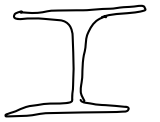


SEMI-COMPACT SECTION

It developes at extreme fibre & can't develope plastic hige due to local buckling



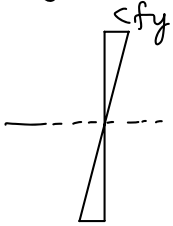
stress diagram

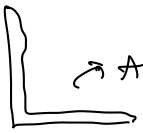


(I-section)

SLENDER SECTION

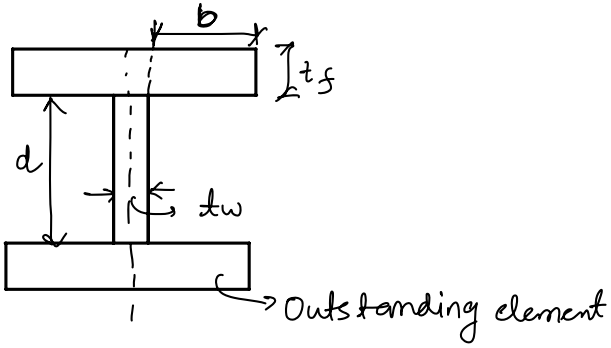
In this section local buckling occurs even before yielding of extreme fibre



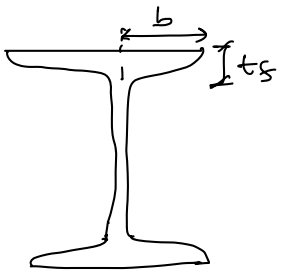


→ Angle section.

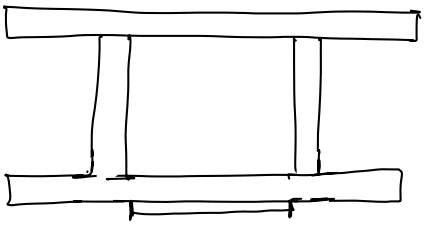
		Ratio	plastic	Compact	Semicompact
Outstanding element of Comp flange	Rolled	b/t_f	9.4ϵ	10.5ϵ	15.7ϵ
	Welded	b/t_f	8.4ϵ	9.4ϵ	13.6ϵ
Internal element of comp flange	Comp due to bending	b/t_f	29.3ϵ	33.5ϵ	42ϵ
	Axial	b/f_t	Not applicable		42ϵ
web of I section	when NA@ mid depth	d/t_w	84ϵ	105ϵ	126ϵ
	Axial comp	d/t_w	Not applicable		42ϵ



Built up section



$$\epsilon = \sqrt{\frac{250}{f_y}}$$



Internal element

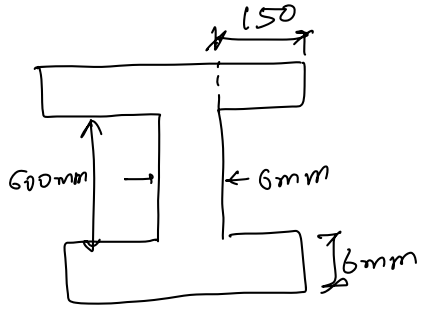
Note

① If different elements of section are under different class then overall section is classified by lower section

② If comp member is plastic, compact & semi compact then effective effective sectional area is gross area. However if holes are not filled deduction should be made for holes

③ For slender section the effective area is calculated by deduction of width of compression plate in excess of semi compact section.

Q) Find effective area of following welded compression member. $f_y = 250\ N/mm^2$



Solution

$$\frac{b}{t_f} = 13.6\epsilon$$

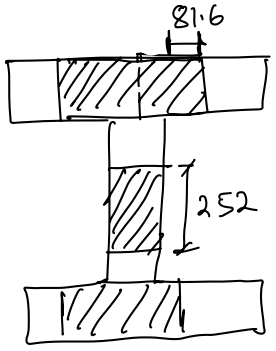
$$b = 13.6 \times 1 \times 6 = 81.6\ mm$$

$$\text{excess} = 150 - 81.6 = 68.4\ mm$$

$$\frac{d}{t_w} = 42\epsilon$$

$$d = 42 \times 1 \times 6 = 252\,mm$$

$$\text{Excess} = 600 - 252 = 348\,mm$$



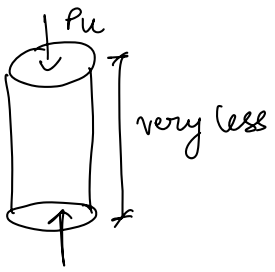
$$\text{effective area} = (81.6 \times 6 \times 4 + 252 \times 6) + 6 \times 6 \times 2$$
$$= 3542.4\,mm^2$$

---

3. Modes of failure of compression member

① Squashing

If length is relatively very small and its components are prevented from local buckling then column is able to attain its full strength.



$$\left\{ P_d = \frac{f_y}{\gamma_{mo}} \times A_e \right\}$$

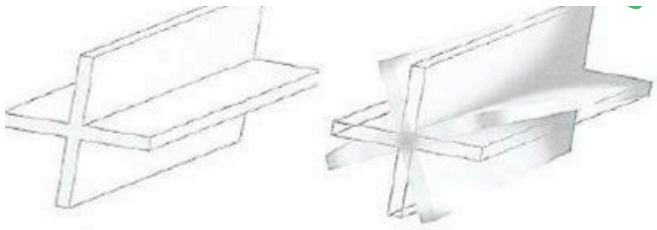
② Local buckling

This failure may occur in the plate element like flange or web due to local buckling, it can be prevented by providing sufficient width to thickness ratio.

③ Overall buckling due to flexure

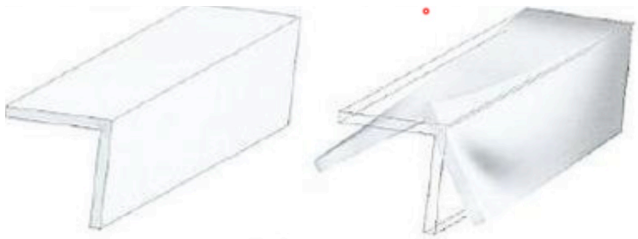
Failure is due to overall buckling about minor axis

④ Torsional buckling



Torsional buckling

⑤ Flexural torsional buckling (SKD 463)



Flexural-torsional buckling

4. Slenderness Ratio

$$\lambda_{max} = \frac{L_{eff}}{r_{min}}$$

Code Table N0 3

λ = Slenderness Ratio

L_{eff} = effective length

r_{min} = Minm radius of gyration

$$= \sqrt{\frac{I_{min}}{A}}$$

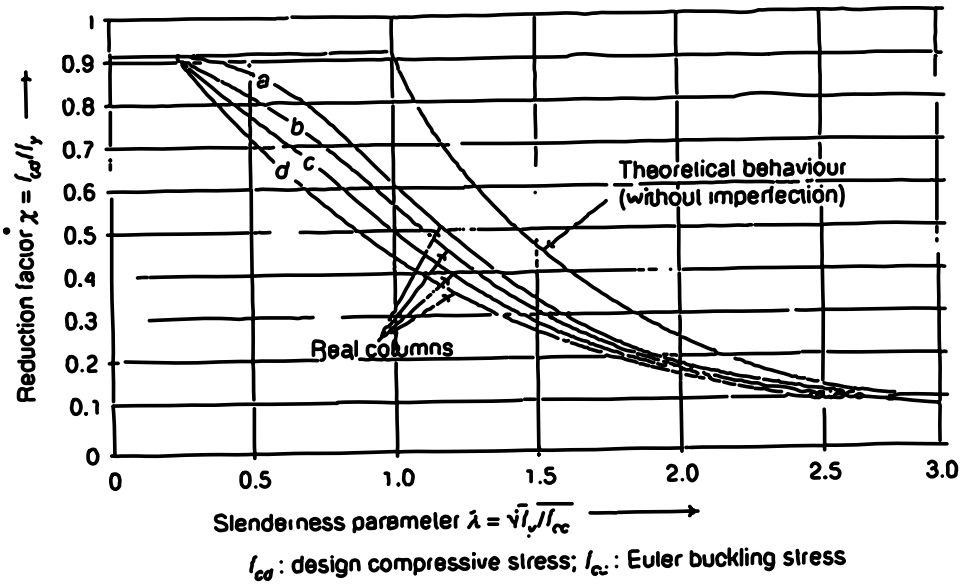
5. Effective length

Same as Tension member.

6. Axial Load carrying capacity (Graphical method)

Common hot rolled sections & built up sections are used to carry axial loads & it generally fails in flexural buckling or flexural torsional buckling the buckling strength is affected by following -

1. Residual stress
2. Initial bow
3. Accidental eccentricity
4. Shape of section.



* To account for above factors large number tests are carried out & column buckling curves a, b, c, d are established. These a, b, c, d are called buckling class.

$$P_d = f_{cd} A_e$$

where, f_{cd} = permissible stress in compression.

$$\boxed{f_{cd} = \chi f_y}$$

χ : Reduction factor.

* Slenderness parameter

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}}$$

f_{cc} = Euler buckling stress = $\frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$

(Leff होगा।)

* There are more chances of overall buckling in solid sections

Classification of class → page 44 (IS800)

* χ can be calculated from Table 8
* f_{cd} can be directly calculated from Table 9.

Class 'a' - least imperfection, class 'b' - maximum imperfection.

7. Axial Load carrying capacity (Analytical method)

* By formula in IS code

$$P_d = f_{cd} A_e$$

$$f_{cd} = \frac{\chi \cdot f_y}{\gamma_{m0}} = \frac{f_y}{\gamma_{m0}} \left(\frac{1}{\phi + \sqrt{\phi^2 - \lambda e^2}} \right)$$

$$\phi = 0.5 \left(1 + \alpha (\lambda e - 0.2) + \lambda e^2\right)$$

α = corresponding to different buckling class

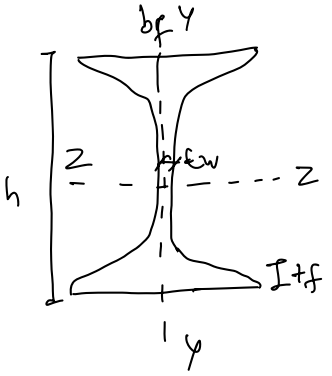
Buckling class	a	b	c	d
α	0.21	0.34	0.49	0.76

$$\lambda e = \sqrt{\frac{f_y}{f_{cc}}} \quad \& \quad f_{cc} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

Note:- If $\lambda e < 0.2$ then column can achieve full plastic resistance (It means buckling is neglected)

Question

Calculate design compressive load for ISHB 350 @ 710.2 N/m . Height of column 3.5m . Column is restrained in the direction and rotation of both ends . It is to be used as an uncased column in a single storey building E250.



$h = 350mm$ $b_f = 250mm$ $t_f = 11.6mm$

$t_w = 10.1mm$, $A = 9221\ mm^2$

$r_{zz} = 146.5mm$. $r_{yy} = 52.2mm$

Solution

* By using graphs & tables

- Classification of buckling class

$$\frac{h}{b_f} = \frac{350}{250} = 1.4 > 1.2$$

$$t_f = 11.6 < 40$$

So section is under class 'a' → z-z axis

class 'b' → y-y axis

- Slenderness ratio.

($K = 0.65$)

$$\frac{KL}{r_{zz}} = \frac{0.65 \times 3.5 \times 10^3}{146.5} = 15.52$$

From IS 800, page 40

class 'a' $\frac{KL}{r} = 15.52 : f_y = 250$

$f_{cd} = 226.44\ N/mm^2$

Design load = $A_e \cdot f_{cd}$

(about z-z) = $9221 \times 226.44 = 2088.06\ KN$ (about z-z axis)

Ans

$$\frac{KL}{r_{yy}} = \frac{0.65 \times 3.5 \times 10^3}{52.2} = 43.58$$

f_{cd} = 201.7 N/mm² [class b]

Design load = 9221 × 201.7 = 1859.87 KN

(about y-y)

* By Analytical method (formula)

Buckling class same as earlier

α = 0.21 (for z-z axis)

= 0.34 (for y-y axis)

For z-z axis,

$$\lambda_e = \sqrt{\frac{f_y}{f_{ce}}} = \sqrt{\frac{f_y\left(\frac{KL}{8}\right)^2}{\pi^2 E}} = \sqrt{\frac{250\left(\frac{0.65 \times 3.5 \times 10^3}{146.5}\right)^2}{\pi^2 \times 2 \times 10^5}}$$

= 0.175 < 0.2 (considering 0.2)

$$\phi = 0.5\left[1 + \alpha(\lambda_e - 0.2) + \lambda_e^2\right]$$

$$= 0.5\left[1 + 0.21(0.2 - 0.2) + 0.2^2\right]$$

$$= 0.52$$

$$f_{cd} = \frac{f_y / \gamma_{m0}}{\phi + \sqrt{\phi^2 - \lambda_e^2}} = \frac{250/1.1}{0.52 + \sqrt{0.52^2 - 0.2^2}}$$

= 227.2 N/mm²

Design load = $f_{cd} \cdot A_e$ = 227.2 × 9221 = 2095 KN.

For y-y axis

$$\lambda_e = \sqrt{\frac{f_y}{f_{ce}}} = \sqrt{\frac{f_y\left(\frac{KL}{r_{yy}}\right)^2}{\pi^2 E}} = \sqrt{\frac{250\left(\frac{0.65 \times 3.5 \times 10^3}{52.2}\right)^2}{\pi^2 \times 2 \times 10^5}}$$

= 0.49

$$\phi = 0.5\,(1 + 0.34\,(0.49 - 0.2) + 0.49^2)$$

$$= 0.67$$

$$f_{cd} = \frac{f_y / \gamma_{mo}}{\phi + \sqrt{(\phi^2 - \lambda^2)}} = \frac{250/1.1}{0.67 + \sqrt{0.67^2 - 0.49^2}}$$

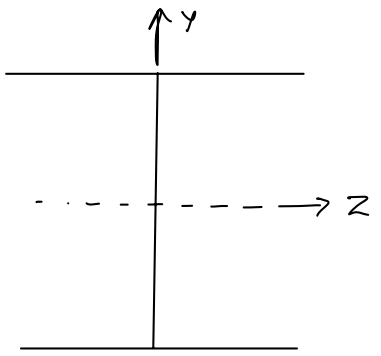
$$= 201.67\ N/mm^2$$

Design load = $A_e \cdot f_{cd}$

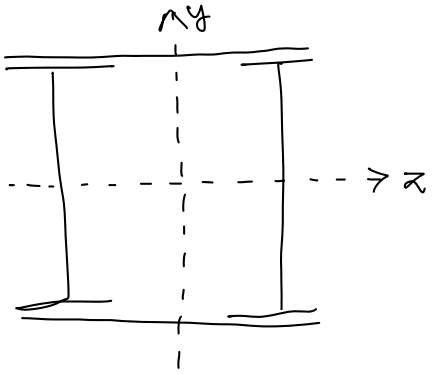
$= 9221 \times 201.67$

$= 1859.59\ KN$

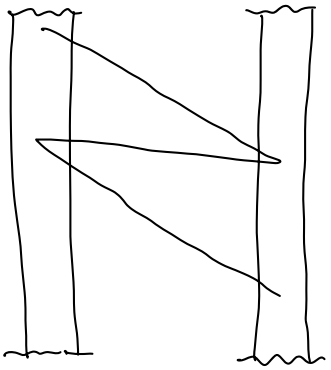
7. Built up columns



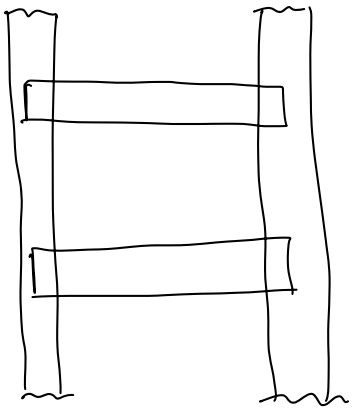
$I_{zz} > I_{yy}$



$I_{yy} > I_{zz}$



Lacing



Battening

① Laced column is adopted in case of eccentrically loaded columns and battened column is designed in case of axially loaded column

② Built up columns are provided if very heavy load is acting on column

③ Sometimes, $I_{zz} = I_{yy}$ is required from design point of view, in that case built up is preferable

④ Primary function of connecting system is

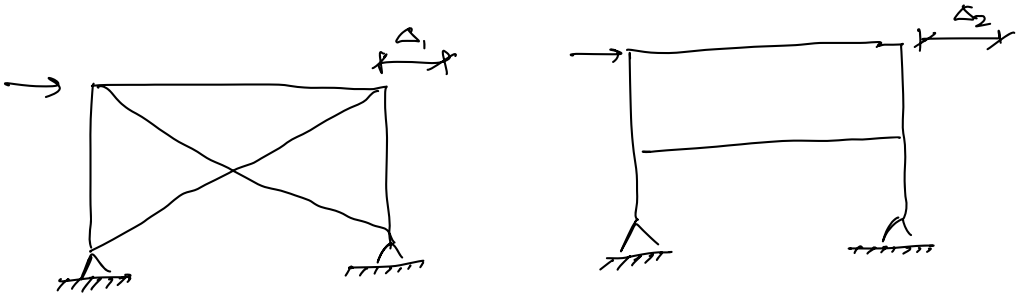
* Hold the main members at place and for equalising stress
* Points of intermediate support.

* Laced column

- For laced column we need to design main member & and column & its spacing
- Spacing of main members should be such that

$$I_{yy} > I_{xx}$$

- Rigidity of laced column is more than battened column

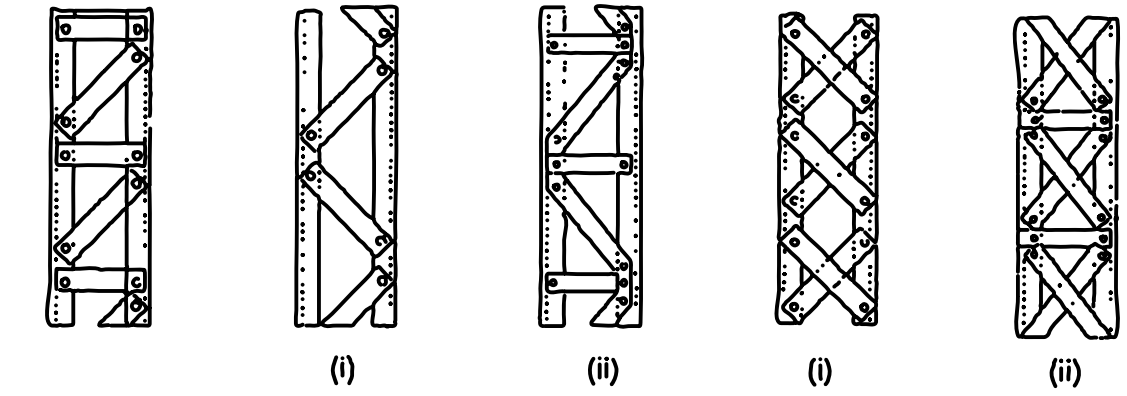


$\{\Delta_1 > \Delta_2\}$

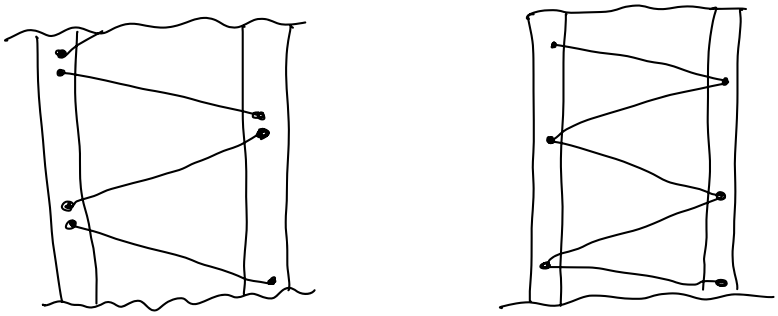
④ Advantages of lacing system & modes of failure

* Failure of column as a whole
* Failure of main component
* Failure of lacing

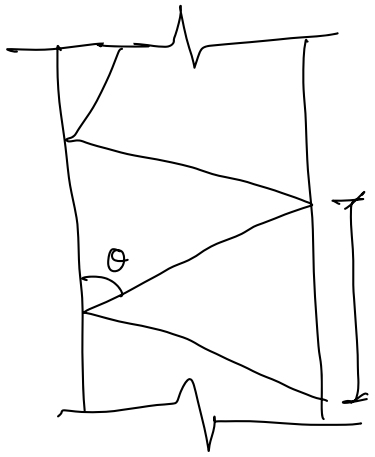
(5) Different types of lacing system



(6) Single lacing non-intersecting is preferable because failure of one intermediate connections would not lead to increase in the distance b/w intermediate connection



(7) Permitted inclination of lacing with longitudinal axis of main member in 40° - 70°



(8) By increasing inclination of lacing the unsupported length of main character is reduced.

(9) Double lacing is provided when capacity of single lacing is not sufficient

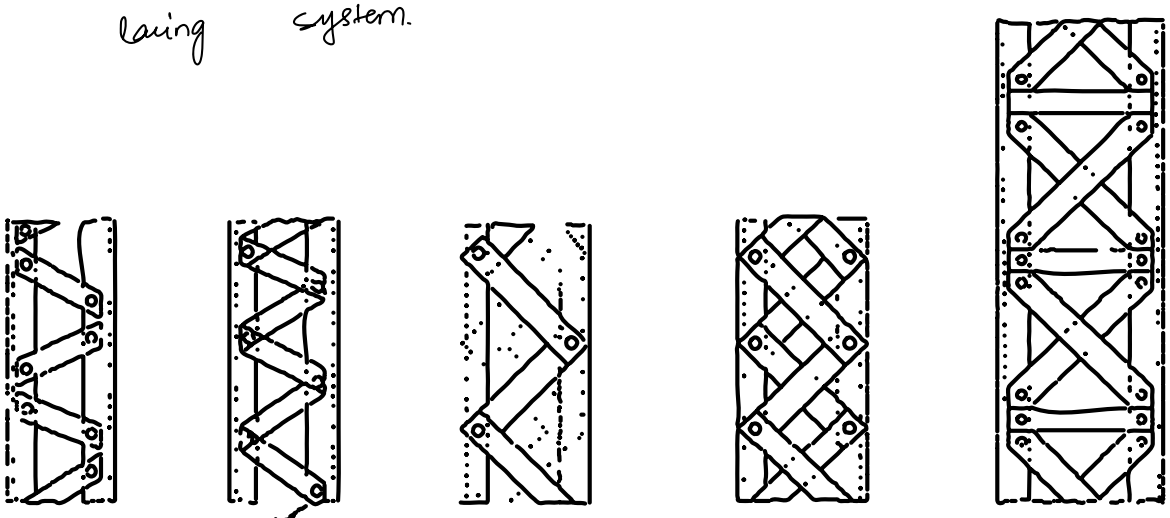
(10) At the top & bottom of laced column battens called as end battens or tie plates are provided.

(11) End batten ensure the balancing of unbalanced forces in lacing & makes the ends rigid.

(12) Lacing must be uniform in full length of member.

(13) Lacing on opposite face must be mirror image but lacing on adjacent face can be staggered.

(14) Cross members are not desirable in case of double lacing system.



(a) Single flat lacing non-intersecting (b) Single flat lacing inter-secting (c) Single-flat lacing non mirror image (not recommended) (d) Double-flat lacing intersecting (e) Double-flat lacing with batten (not recommended)

Fig. 8.20 Lacing systems

* Design of Lacing

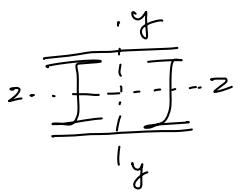
1. Slenderness ratio of laced column shall be 5% more than calculated using $\frac{L_{eff}}{r_{min}}$

$$\lambda_{laced} = 1.05\lambda$$

This increment is to account for shear deformation.

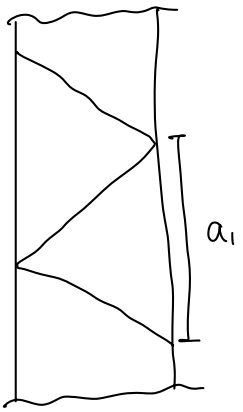
2. The spacing b/w members should be such that

$I_{yy} \not\approx I_{zz}$



3. Angle of inclination -40 to $70°$

4. Maximum spacing b/w intermediate connection should be such that

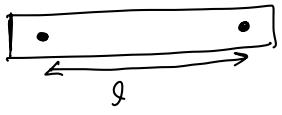


$$\frac{a_1}{r_{min,one}} \not> \min \begin{cases} 50 \\ 0.7 \times \text{Slenderness of whole column} \end{cases}$$

5. Effective length of lacing

$L_{eff} = l$ (for single lacing)

$= 0.7l$ (for double lacing & welded lacing)



6. Maximum slenderness of single lacing $\not> 145$.

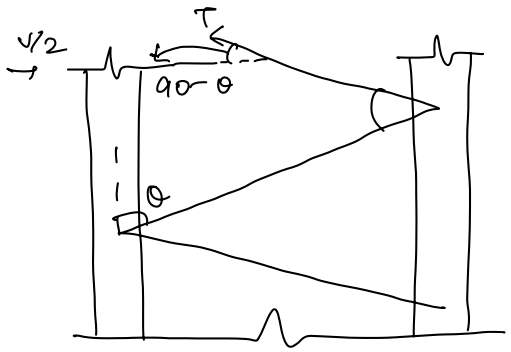
7. Minimum width of lacing is 3 times dia of bolt.

8. Minimum thickness of lacing $\geq \max \begin{cases} \frac{L_{eff}}{40} \text{ (single)} \\ \frac{L_{eff}}{60} \text{ (double)} \end{cases}$

9. Design force in lacing

Lacing should be designed for tension and

compression due to shear force in column. There force can be shear force in column due to bending Lateral loading or accidental eccentricity - Its value is taken as 2.5% of axial load for axially loaded column This force is equally divided b/w opposite faces of laced column. so force on one lacing plane is $\frac{1}{2}$ (2.5% of Pu)



$$\frac{V}{2} = T \cos(90-\theta)$$

$$T = \frac{V}{2} \operatorname{cosec} \theta$$

where, V = 2.5% of Pu

Capacity of lacing bar

- Tension

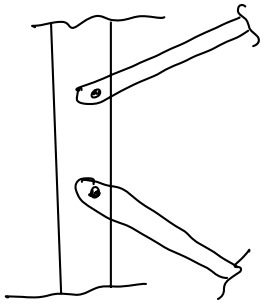
$$T_d = \frac{0.9 f_u}{\gamma_{m_1}} A_{net}$$

- Comp

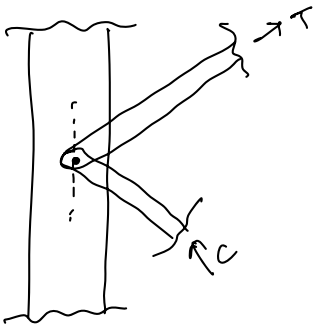
$$P_d = f_{cd} \cdot A_e$$

force in lacing should be less than capacity

Connection of lacing



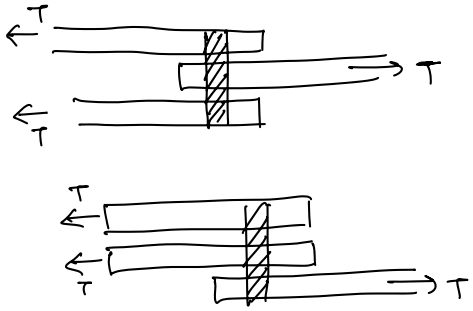
- Single lacing non-intersecting bolts shall be designed for Tension and compression of lacing calculated above.



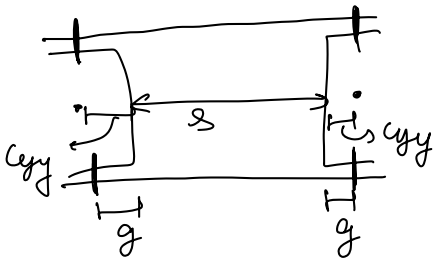
Net force on bolt = $T\cos\theta + C\cos\theta$

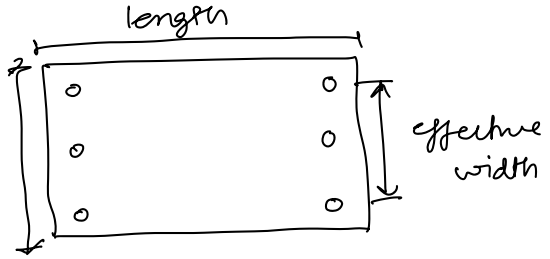
$= \frac{V}{2}\frac{\cos\theta}{\sin\theta} + \frac{V}{2\sin\theta}\cos\theta$

Net force on bolt = $V\cot\theta$.



* End batten plates





- length is kept end to end lateral dimension of built up column
- width = effective width + 2x edge distance

where

effective width $\geq$ max^m { • 2 x width of each column. • $s + 2c_{yy}$

- Thickness $\geq \frac{1}{50}(s+2g)$

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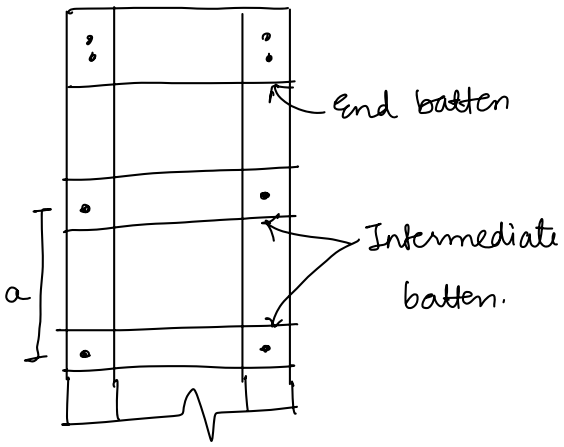
* Battened column



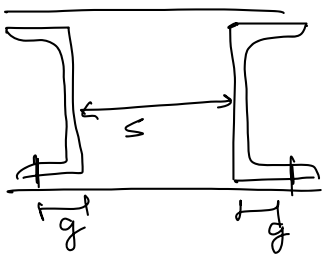
- Battened column is not suitable for heavy axial load and eccentric load
- No of battens such that column is divided into not less than 3 parts. It means minimum no of intermediate batten is 2.

- Slenderness ratio = 1.1 times λ of column
- Slenderness of individual column

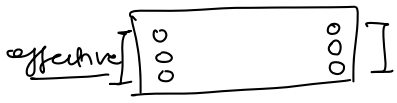
$$\frac{a}{(r_{min})_{single}} < \text{min}\begin{cases} \cdot 50 \\ \cdot 0.7\lambda \text{ of whole column} \end{cases}$$

- width of batten
  - For intermediate batten
    - effective width

$$\text{max}\begin{cases} \frac{3}{4}(s+2c_{yy}) \\ 2\times\text{width of one member} \end{cases}$$



- Total width = effective width + 2× edge distance

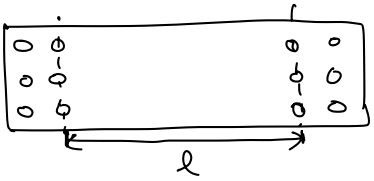


  - End batten
    - effective width

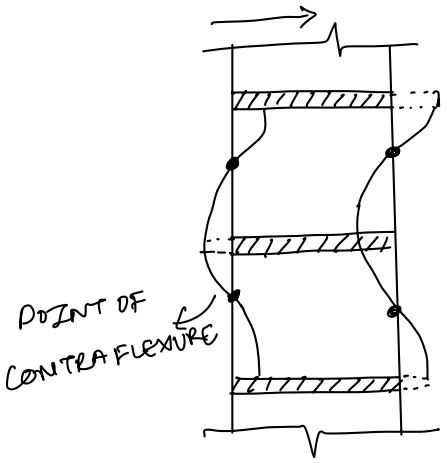
$$\text{max}\begin{cases} \cdot 2\times \text{width of individual colm} \\ \cdot (s+2c_{yy}) \end{cases}$$

- Thickness of batten

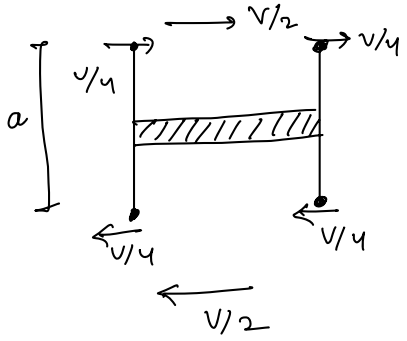
$$t \geq \frac{l}{50}$$



- Battened column shall be design for shear force 2.5% of axial load + additional shear force in column if present.



- Batten shall be designed for shear force & bending moment



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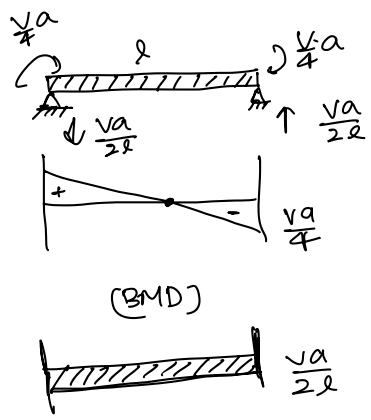


(BMD)

- Batten shall be checked for bending.

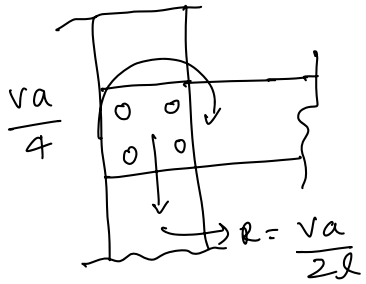
$$f_{max} = \frac{M_{max}}{Z} = \frac{Va/4}{\frac{bt^2}{6}} \leq \frac{f_y}{\gamma_{m0}}$$

Yielding FOS = 1.1

- Batten shall be checked for shear

$$\tau_{max} : \frac{V}{bt} = \frac{Va}{2lbt} \leq \frac{f_y}{\sqrt{3}\gamma_{m0}}$$

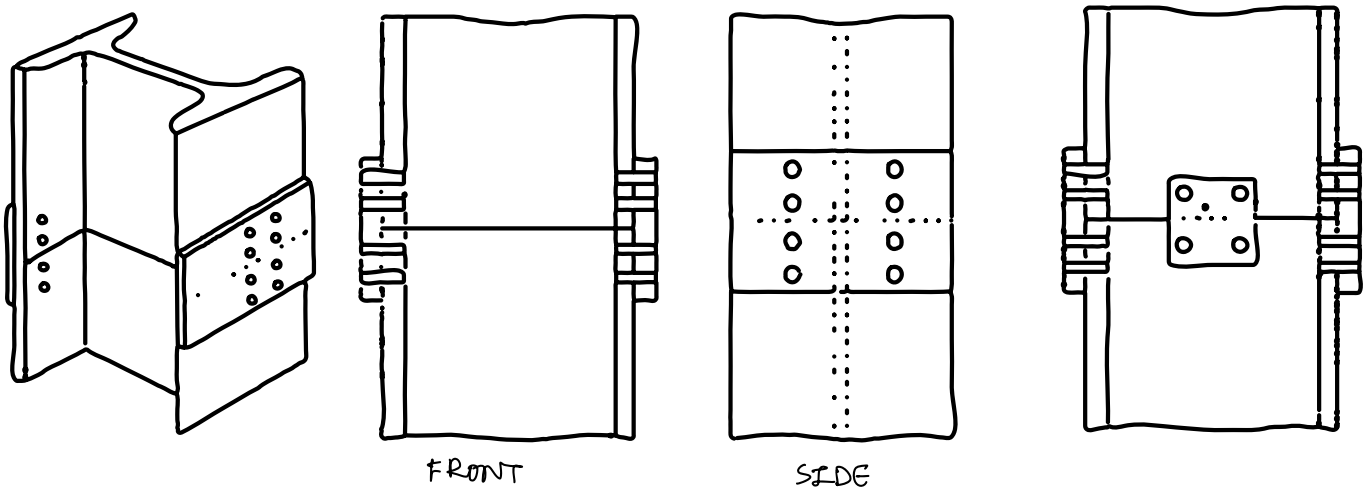
- Connection shall be designed for bracket type &



SKD 3rd edition example pg 527.
11.15

* Column splice

(SKD pg 498)



(a) Column flanges having complete bearing

(b) web splice for shear.

* Splicing is used due to following reasons
  - → Change in section due to change in load
  - → To make member of desired length by using the member of standard length

* The ideal location of splicing is at a height h/4 from top & bottom.

* If column ends are milled (smooth / machine cut) then load is transfered through bearing not by splice. However designers prefer to design splicing for $\frac{P}{2}$ in this case also.

* If column ends are not milled then complete force is transferred through splicing

* Column subjected to axial load & moment